The Measurement and Reduction of Microphonic Noise in Vacuum Tubes

By D. B. PENICK

The microphonic response of different types of vacuum tubes to the same mechanical agitation covers a 70 db range of levels. Tubes of the same type, on the average, cover a range of about 30 db. These response levels are too sensitive to minute variations in testing conditions to be measurable with any great precision, but values which are reproducible to within 5 db are obtainable with a laboratory test set comprising a vibrating hammer agitator, a calibrated amplifier, and a thermocouple galvanometer indicator. Sputter noise is made measurable by frequency discrimination methods.

Minimum microphonic disturbance under given service conditions is attained by using the less microphonic types of tubes which are available, by selecting the quieter tubes of a given type for use in positions sensitive to mechanical disturbance, and by protecting the tubes from mechanical and acoustic vibration. Examples of quiet triodes are the Western Electric No. 264B (filament) and No. 262A (indirectly heated cathode). Indirectly heated cathode type tubes are intrinsically less microphonic than filamentary types. Further microphonic improvement in the tubes themselves is made difficult by requirements for favorable electrical characteristics. Well designed cushion sockets can reduce microphonic levels by as much as 30 db, and other methods of cushioning, more expensive and less compact, can extend the reduction even farther. Sputter noise can be eliminated almost entirely in most types of tubes by commonly applied design features and manufacturing methods.

A MAJOR problem which has had to be met by every engineer who has designed a high gain amplifier is that of elimination or reduction of noise. Noise of one kind or another, extraneous to the desired signal, is always present in any amplifier, and sets a lower limit on the smallness of the signal which can be amplified without intolerable interference. In many experimental and commercial amplifiers, the technical and economic obstacles to noise reduction necessitate a compromise between inherent noise level and sufficient volume range for ideal reproduction. The possible sources of this noise are numerous and include power supply, faulty contacts, insulation leaks, pick-up from stray fields, and many other disturbing elements. Among the most persistent types of noise, however, requiring particularly careful design for their elimination or satisfactory reduction, are three which originate in the vacuum tubes themselves, namely, fluctuation noise, microphonic noise, and sputter noise.

Fluctuation noise has been treated at some length by Schottky,[1]

[1] W. Schottky, *Ann. der Phys.*, v. 57, p. 541, 1918; v. 68, p. 157, 1922. *Phys. Rev.*, v. 28, p. 74, 1926.

the discoverer of one of its sources and by several other investigators.[2] It is the fundamental noise arising from the circumstance that the electron current is a stream of discrete particles rather than a continuous flow. For ordinary types of low power tubes of good design, over the audio band of frequencies, the root-mean-square amplitude of this noise is equivalent to about 1 microvolt (120 db below 1 volt) of noise voltage applied to the grid of the tube. G. L. Pearson,[2] in a recent paper, has pointed out that for the best signal-to-noise ratio, the input impedance should be so large that the thermal noise arising in this impedance predominates over the fluctuation noise arising in the tube. In many broad-band or high-frequency systems, however, such an ideal condition is practically unattainable, and fluctuation noise remains as a limiting factor.

It is with the second type, microphonic noise, that we are particularly concerned here, though sputter noise is also of interest and will be dealt with briefly in a later paragraph. Microphonic noise, as the name is usually applied, is the familiar gong-like sound which is always produced when a vacuum tube, followed by a sufficiently high-gain amplifier and a sound reproducer, is subjected to a mechanical shock. Its origin is in the vibrations of the various elements of the tube, which make minute, more or less periodic changes in the spacings of the elements and therefore make corresponding changes in the plate current, whose value at every instant depends on these spacings. Its intensity in a given tube depends on the type and intensity of agitation to which the tube is subjected. For a given agitation, microphonic noise may be reduced either by stiffening and damping the tube structure, thereby reducing the amplitude and duration of vibration of the elements, or by cushioning the tube so that it receives only part of the original agitation.

In order to treat the problem of noise reduction intelligently, it is necessary to have a measure of the effectiveness of treatments applied. To this end, the properties of microphonic response in vacuum tubes have been studied, and a test set has been designed and built for laboratory use which affords a quantitative measure of microphonic response in tubes, and of effectiveness of cushioning in cushion sockets. Some of the more important characteristics of microphonic noise will now be considered.

[2] "The Schottky Effect in Low Frequency Circuits," J. B. Johnson, *Phys. Rev.*, v. 26, pp. 71–85, July, 1925.

"A Study of Noise in Vacuum Tubes and Attached Circuits," F. B. Llewellyn, *Proc. I.R.E.*, v. 18, pp. 243–265, Feb., 1930.

"Shot Effect in Space Charge Limited Currents," E. W. Thatcher and N. H. Williams, *Phys. Rev.*, v. 39, pp. 474–496, Feb. 1, 1932.

"Fluctuation Noise in Vacuum Tubes," G. L. Pearson, *Physics*, v. 5, p. 233, September, 1934. Also published in this issue of *Bell Sys. Tech. Jour.*

Factors Affecting Microphonic Noise Levels

In the first place, it may be pointed out that the production of microphonic noise in commercial types of vacuum tubes is an extremely complicated phenomenon. Each individual component of the mechanical structure is a complete vibrating system having several modes of vibration and natural resonant frequencies, and usually very little damping as compared with electrical circuits. These components, all coupled together mechanically in various ways, form a mechanical network much more complex than the electrical networks encountered in communication engineering practice.

The complexity of the mechanical vibration is reflected in the complex character of the noise itself, and is admirably illustrated by the frequency-response characteristics published by Rockwood and Ferris,[3] and by similar characteristics obtained in the course of this work. It is further demonstrated by the experimental fact that when a large group of supposedly identical tubes is tested by applying the same mechanical vibration to each tube in turn, mounted in the same socket, the response levels of individual tubes may differ from each other by as much as 30 db for representative types of tubes. Such a magnitude of variation would not be expected to result from the comparatively small dimensional variations tolerated in manufacture, and must be explained by the exaggerating effect of intercoupled mechanical resonances in a complicated vibrating system. A curve showing a typical distribution of microphonic response levels in a group of tubes of the same type measured under identical conditions of agitation is shown in Fig. 1. The general shape of this curve is characteristic of any function subject to random variations about a mean, and the range of levels included between the quietest and the noisiest tubes, approximately 30 db, is about average for different types of tubes. Tubes of exceptionally firm construction and of fairly wide spacing, may vary over as small a range as 15 or 20 db, while tubes in which there is a possibility of slight looseness of parts, may vary over as great a range as 40 db or even more.

The nature and intensity of the agitation, the vibrational characteristics of the tube mounting, and the type and degree of mechanical coupling between the tube and its mounting also play an important part in the determination of the microphonic response of a particular tube, since the tube and its closely coupled mounting make up a single vibrating system. The reason for considering the coupling apart from the mounting is that it is usually of the pressure-friction variety and is subject to random variation.

[3] "Microphonic Improvement in Vacuum Tubes," Alan C. Rockwood and Warren R. Ferris, *Proc. I.R.E.*, v. 17, pp. 1621–1632, Sept., 1929.

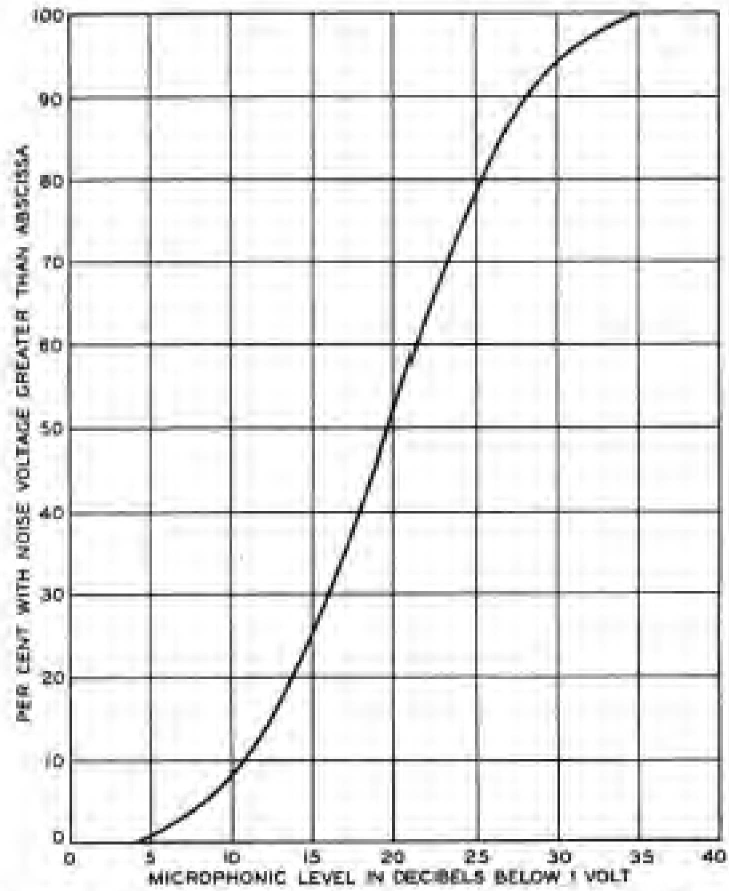

Fig. 1.—Typical distribution of microphonic noise levels produced by a constant, artificial, mechanical stimulus (Western Electric No. 102F Vacuum Tube).

It is found experimentally that with no type of commercial socket which has been tested can a tube be removed and reinserted, or even be left in the socket for a period of time subject to incidental jars and temperature fluctuations, with the expectation of perfectly reproducing a previously measured microphonic level. The sort of random variation which is usually found is illustrated in the reproducibility chart of Fig. 2. In this chart, each point represents two separate observations of microphonic level made on the same tube in the same apparatus, the tube having been removed and reinserted between the two observations. The two levels thus measured are represented by the abscissa and ordinate, respectively, so that if the measurements were perfectly reproducible, all of the points would lie on a straight line making an angle of 45 degrees with the coördinate axes and passing through the origin. The amount of maximum scattering here is about 5 db and may be considered an average value. In some cases, with commercial

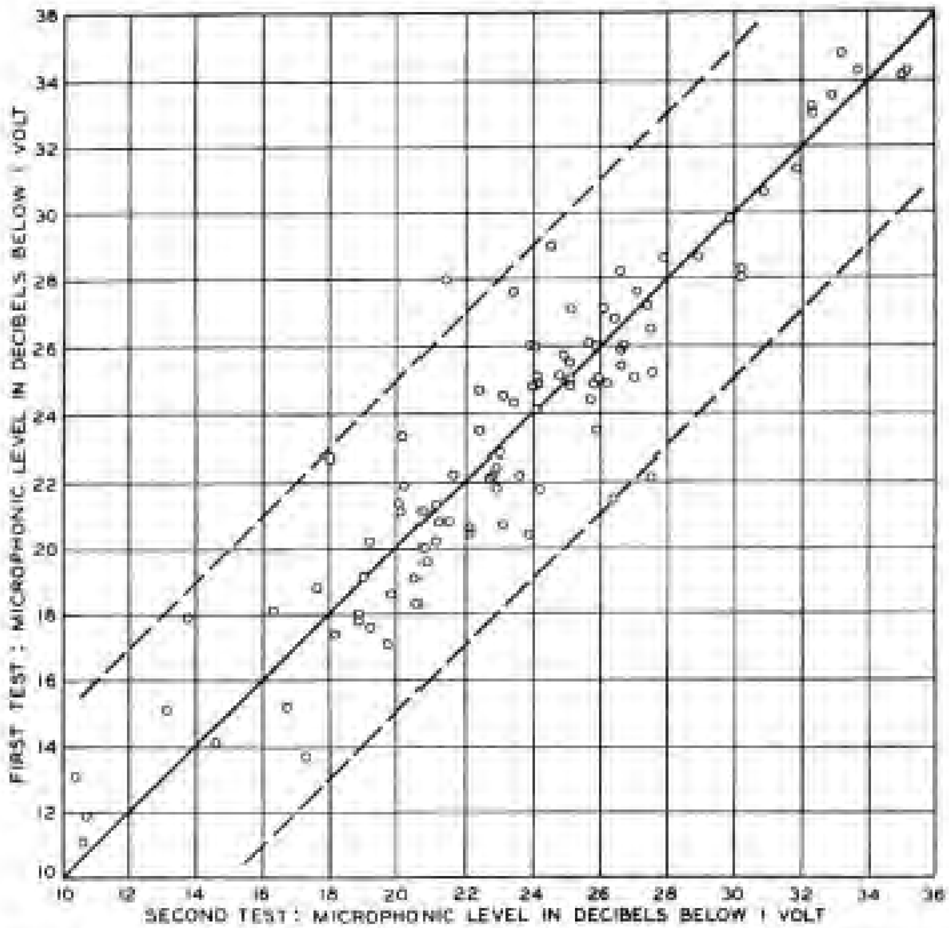

Fig. 2—Reproducibility of microphonic noise level measurements using a commercial socket with a constant, artificial, mechanical stimulus (100 No. 102F Tubes).

sockets, it has been observed to be as low as 3 db and in others as high as 8 db.

In order to show that this random variation is not due to the tube itself, experiments have been made with two forms of suspension which minimize the reaction of the mounting on the vibration of the tube and so reduce as far as possible the effect of variation in coupling. In one set-up, the tube is hung by a single thread of rubber, stretched to its elastic limit, the electrical connections being made by very light, flexible leads fastened with light clips directly to the prongs of the base. In the other, the tube is clamped lightly between two large blocks of very soft sponge rubber, and the electrical connections are made through mercury cups into which the base prongs dip. In both cases, the agitator is a light pendulum striking the base or bulb of the tube. The two mountings give very similar results, and are charac-

terized by very much less scattering than any normal tube mounting, as may be seen in the correlation chart of Fig. 3, which is typical of all of the tests made with these light suspensions. The maximum scattering here is only about 1 db.

Going to the opposite extreme in tube mounting, similar tests have been made with the tube base held tightly in a split metal clamp,

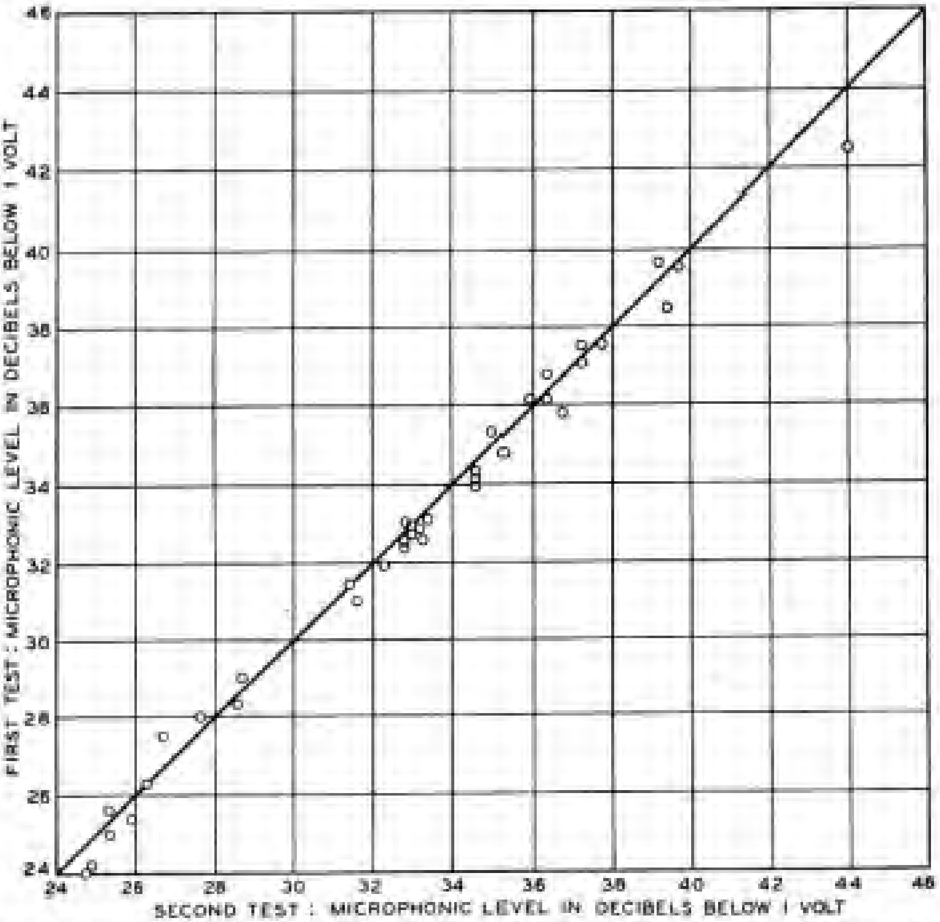

Fig. 3—Reproducibility of microphonic measurements using a rubber clamp tube mounting with a constant, artificial, mechanical stimulus (37 No. 102F Tubes).

which itself is bolted rigidly to a heavy base. As is to be expected, the observed levels vary widely and erratically for successive insertions of the tube, and the mere tightening or loosening of the thumb-screw controlling the pressure of the clamp on the base in some cases changes the level by as much as 10 db.

As for the nature of the applied agitation and the vibrational characteristics of the tube mounting, a countless number of combinations

of these exists, each of which would agitate the tube in a different way. However, from tests made with a variety of mounting arrangements for the tube under test and a variety of degrees of intensity and points of application of forms of impact agitation, it may be concluded that in practical set-ups these factors may be varied widely without changing the general nature of the microphonic level measurements greatly. That is, the form and breadth of the distribution curve and the scattering of the points on the reproducibility chart for any typical group of tubes are likely to be quite similar to Figs. 1 and 2, respectively, for almost any practical impact agitator.

Although the general nature of the results obtained with various combinations of these agitator and mounting arrangements is about the same for all of them, there are certain particular differences, which show up chiefly in two characteristics. One is that the mean noise level of a group of tubes is in general not the same for different mountings and methods of agitation. That this must be true is fairly obvious and needs no comment. The other is illustrated in Fig. 4, which is a correlation chart showing typical results of measurements

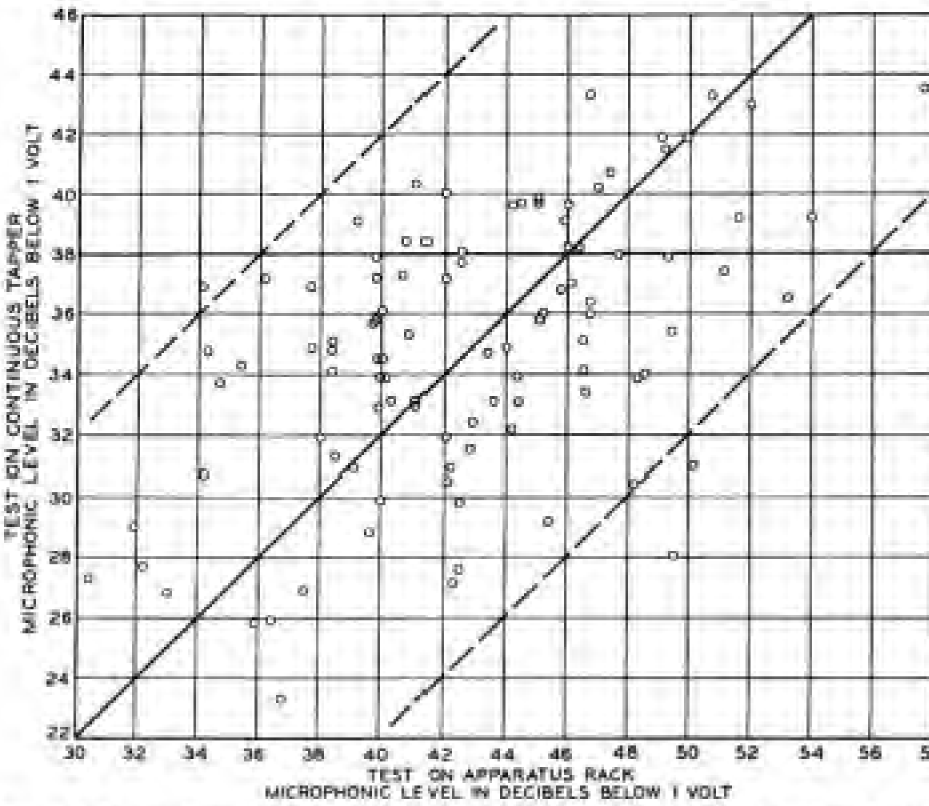

Fig. 4—Comparison of two tube mountings with a constant, artificial, mechanical stimulus (100 No. 102F Tubes).

of the same group of tubes on two different agitating systems. One system in this case consists of a rectangular slate block vibrated by repeated blows of an electrically operated hammer. The other system consists of a steel panel carrying the tube under test, mounted on an apparatus rack which is vibrated by a single blow from a steel ball falling as a pendulum against the rack. The points on this chart scatter about an ideal line over a band about twice as broad as that in Fig. 2 where a test is made and repeated on the same testing unit. It may also be observed that the mean noise levels produced by the two systems are different, about 35 and 43 db below one volt respectively.

The effect of varying the intensity of agitation is shown in Fig. 5.

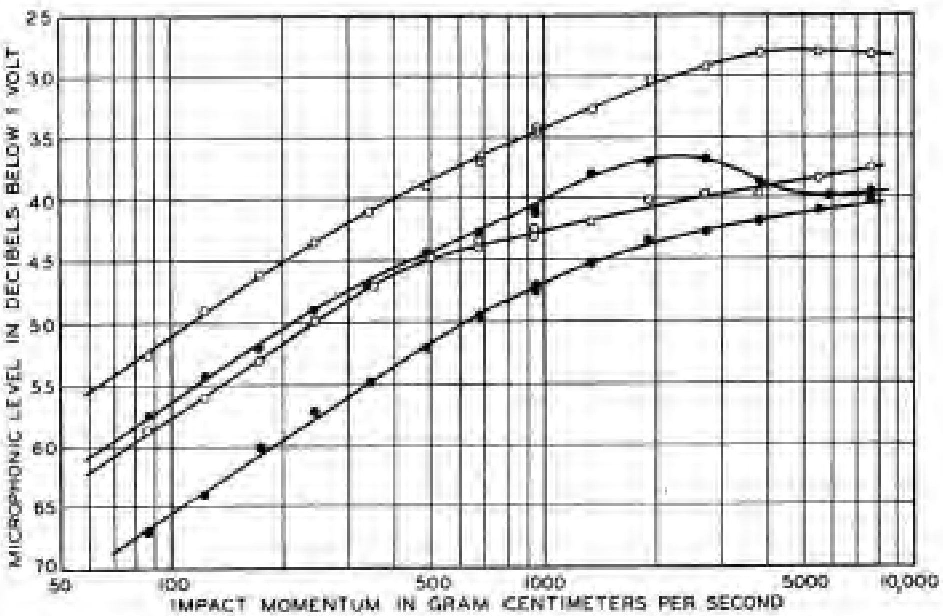

Fig. 5—Effect of intensity of agitation on 4 No. 264B Tubes.

The four curves represent four No. 264B Tubes tested under the same conditions. In making the measurements, the tube under test is mounted in an ordinary socket on a heavy base, which is agitated by means of a pendulum swinging against it and making one rebound. From measurements of the initial swing of the pendulum, its rebound, and its mass, the total momentum imparted to the tube mounting during the impact can be calculated. This quantity is plotted as abscissa in the figure and is proportional to the initial velocity imparted to the tube mounting at the point of impact. Different values of momentum are obtained by varying the initial swing and the mass of the pendulum. At the lower values of momentum, the observed

points lie, within the limits of experimental error, on parallel straight lines so drawn that along them the microphonic noise level expressed in volts is proportional to the initial velocity of the tube mounting. Some such relation as this would be expected to hold as long as the response of the system is linear. The departure from this law at higher values of momentum, then, probably indicates non-elastic motion either of elements of the tube with respect to one another or of the tube with respect to the socket. It may be noted in passing that the No. 264B Tube is exceptionally rigid in structure and that in more loosely constructed tubes, the straight line part of the response curve ends at much lower intensities of agitation.

Since the noise energy is spread over a band of frequencies, the microphonic response observed in any given reproducing system depends also on its frequency-response characteristic. In the usual type of volume indicator, the response is substantially uniform over the audio range of frequencies, but where the final auditory sensation is being considered, the overall characteristic is modified by that of the ear of the listener.[4] The effect of changing the overall response characteristic is illustrated for one particular case in Fig. 6 and Table I.

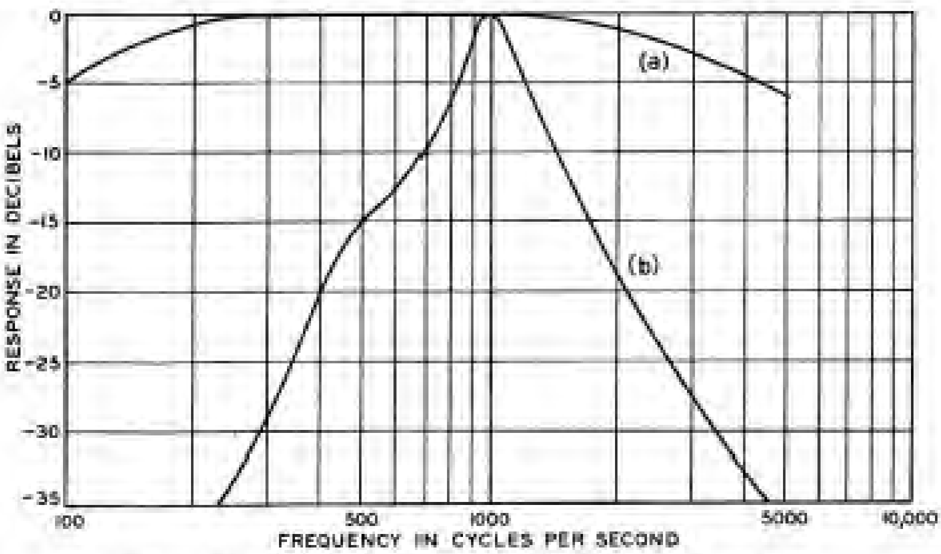

Fig. 6—Microphonic noise amplifier frequency characteristics.

Here, two sets of measurements have been made on each of three types of tubes, one set using an amplifier having a fairly uniform gain characteristic, curve (a), Fig. 6, and the other set using a weighted amplifier, weighted as in curve (b) in the figure. The same agitator and

[4] "Speech and Hearing," H. Fletcher. D. Van Nostrand Co., 1929.

TABLE I

MICROPHONIC LEVELS IN DB BELOW 1 VOLT

Type Tube	Amplifier (a)	Amplifier (b)	Difference
264B	37.9	63.2	25.3
102F	29.7	44.7	15.0
231D	18.2	38.9	20.7

indicator are used in both sets of measurements. Table I gives the mean noise levels for each of the three types of tubes and the differences between the values obtained for each type with the two amplifiers. The results represent about ten tubes of each type. The weighted amplifier, of course, gives the lower levels for all tubes since the noise components at all frequencies except 1000 c.p.s. are amplified less by this amplifier than by the more uniform amplifier. The magnitude of the difference in level depends on the frequency spectrum of the microphonic noise being measured and in general is different for different types of tubes as in this illustration.

Still another important factor which affects the microphonic response of a given system is the relation between the rate of variation of the noise intensity and the time-response characteristic of the system as a whole, usually determined by the indicator. The indicator may be a meter, oscillograph, or other device, or it may be the ear of a listener. A slow moving indicator would respond less to a pulse of noise, such as might be produced by a single shock to a tube, than a more rapidly responding indicator having the same sensitivity to a steady signal. The time required for the ear to reach its maximum response to a suddenly applied sound is about 0.2 second.[5]

The degree of importance of the time-response characteristic of the indicator in measuring transient pulses may be inferred from Table II. This table gives the results of two sets of measurements made on the same three groups of tubes with a single impact type of agitator. The

TABLE II

MICROPHONIC LEVELS IN DB BELOW 1 VOLT

Type Tube	0.2 Second Indicator	2.0 Second Indicator	Difference
264B	37.9	50.5	12.6
102F	29.7	37.2	7.5
231D	18.2	25.2	7.0

[5] "Theory of Hearing; Vibration of Basilar Membrane; Fatigue Effect," G. V. Bekesy, *Physikalische Zeitschrift*, v. 30, p. 115, March, 1929.

two sets differ only in the indicators used. One requires approximately 2 seconds to reach its maximum deflection with a steady impressed signal, and the other requires about 0.2 second. The differences in level corresponding to different types of tubes do not vary greatly, but are nevertheless appreciable. They are, to some extent, a measure of merit of the tube, for a larger difference indicates higher damping of the microphonic disturbance, and high damping is of course desirable.

A Microphonic Noise Measuring Set

The type of test set which has been built in the course of this study for use in the laboratory, comprises an arbitrary standard of agitation, a calibrated amplifier, and an indicating instrument. The agitator consists of a heavy, rectangular slate base at one end of which are mounted sockets for several types of tubes. At the other end is an electrically driven vibrating armature carrying a hammer which strikes about 9 blows per second against a steel block bolted firmly near the center of the slate base. This unit is set on a thick felt pad in a felt lined copper box which provides electrical shielding and some degree of sound-proofing. The sockets used (except those for the bayonet-pin bases) are of the type in which contact springs push each base prong firmly to one side, against the body of the socket. This type has been found to stand up well under repeated insertions and withdrawals of tubes and gives as good correlations between repeated microphonic measurements as any type which has been tried.

The amplifier is basically a simple resistance-choke coupled unit having a frequency-response characteristic which is essentially flat (within 3 db) between 80 and 30,000 c.p.s. The tube under test, whose plate voltage is supplied through an 80-henry choke, works directly into a 100,000-ohm potentiometer, variable in 10 db steps, whose output is connected to the input of the amplifier. The indicator is a sensitive thermocouple galvanometer whose scale is marked off in db and half db divisions so that the noise level may be read directly from the setting of the input potentiometer and the position of the indicator. It has been found convenient to think of the noise level in terms of the root-mean-square voltage developed by the tube across the 100,000-ohm load resistance and to use 1 volt as the reference level. Accordingly, unless otherwise noted, the noise levels given herein are expressed as db below 1 volt across a 100,000-ohm load resistance.

In order to correct for time shifts in tube characteristics and battery voltages, provision is made for checking the amplifier calibration at any time by throwing a switch which transfers its input circuit from the tube under test to a local oscillator. This oscillator delivers a

small, fixed output voltage which is measured and set at a predetermined value with the aid of another thermocouple galvanometer. The amplifier gain may be adjusted, by means of a small range, continuously variable potentiometer until the indicator gives the proper reading to correspond with the known level of the applied input. With reasonably steady battery voltages, this calibration is necessary only two or three times in the course of a day's testing. The range of noise levels for which the amplifier is calibrated extends from 10 db above 1 volt to 65 db below 1 volt. This range has been found to include practically all tubes which it has been desired to test with the standard agitator.

The flat amplifier characteristic, which has been described, is normally used for general testing in connection with vacuum tube design work since it gives the highest microphonic level readings and therefore the most conservative picture of the performance of the tube from the standpoint of the designer. Provision is made, however, for switching in a specially designed weighted amplifier such as is used in making routine noise measurements in telephone speech circuits.[6] The frequency characteristic including this unit has already been shown in Fig. 6, curve (*b*), and is designed to compensate for the interfering effect of each component of noise on the average ear plus the effect of the frequency characteristic of the telephone subset. A similar weighting network compensating for the non-uniform frequency response of the ear alone would also be useful, but has not yet been provided.

Nature and Measurement of Sputter Noise

By making a slight modification of the amplifier circuit, this test set may also be used to measure sputter noise. Sputter noise is a descriptive name applied to a class of noises characterized by a harsh crackling or sputtering sound easily distinguished from the gong-like quality of microphonic noise or the steady roar of electron noise. It may occur either with or without agitation and is the result of discontinuous changes in electrode potential such as may be produced by imperfect contact between conducting members in a tube or by intermittent electrical leaks across insulation.

Sputter noise due to agitation is always accompanied by microphonic noise, and though it often contains instantaneous peaks of high intensity which constitute a very disagreeable and annoying type of interference, its total energy content is usually so small that it contri-

[6] "Methods for Measuring Interfering Noises," Lloyd Espenschied, *Proc. I.R.E.*, v. 19, pp. 1951–54, Nov., 1931.

butes very little to the ordinary microphonic level reading. Special methods must therefore be used in order to make measurements of sputter noise which are independent of microphonic noise. One method which has been found to be effective and convenient, is that of frequency discrimination. If the audio frequency components of the total noise are cut out, then microphonic noise is completely eliminated. Sputter noise, however, due to its discontinuous character has, theoretically, an infinite frequency spectrum, and, practically, one which extends at least into the broadcast band of radio frequencies.

In the microphonic noise test set, sputter noise measurement is provided for by switching in a high-pass filter cutting off sharply at 16,000 cycles. Greater sensitivity is also provided by additional stages of amplification to permit the measurement of the lower levels found to be characteristic of sputter noise in this frequency range. A schematic diagram of the microphonic and sputter noise test set is shown in Fig. 7. The weighted amplifier and the calibrating oscilla-

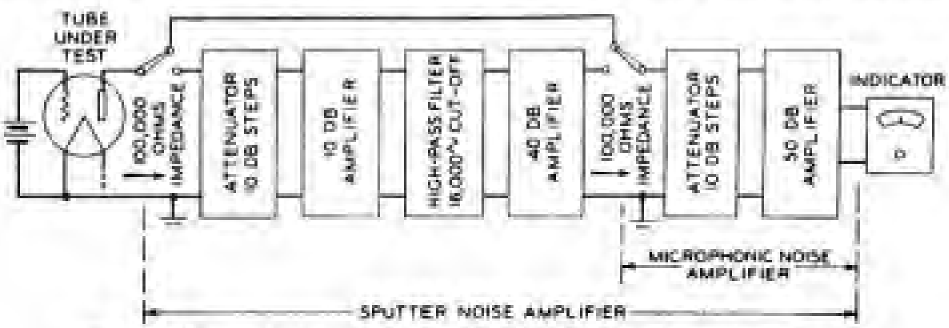

Fig. 7—Microphonic and sputter noise amplifier schematic diagram.

tors (one for microphonic noise and one for sputter noise) have been omitted for the sake of clearness.

Reduction of Microphonic Noise

The reduction of microphonic noise from the view-point of the vacuum tube designer is chiefly a matter of mechanical design and manufacturing technique. The quietest construction is obviously one which has the stiffest electrodes and supporting members, the shortest distances between points of support, and the highest damping of mechanical vibration. The extent to which these features can be incorporated in a practical tube design, however, is limited by the requirements for favorable electrical characteristics. A low filament current, for example, requires that the filament be small in diameter, which renders it more susceptible to vibration than a heavier filament; or if a tube has an indirectly heated cathode, it is a problem to support

the cathode rigidly without conducting away large amounts of heat along the supports. The diameter, length, and spacing of the grid lateral wires are fixed within relatively narrow limits when the desired values of amplification factor and internal impedance are fixed, precluding any important increase in stiffness here; and where high mutual conductance is desired, it is necessary to use relatively close spacings between the elements, under which condition a given amplitude of vibration produces a relatively large per cent change in spacing, and therefore a high microphonic noise level.

The Western Electric No. 264B Vacuum Tube is an example of what has been done in working for a stiff, compact structure. The plate support wires, which also support the whole top of the structure, are short, straight, and as heavy as is practicable, and an extra wire from the press braces the glass bead. One of the most important features of this tube, however, is its filament. In most filament type tubes the vibration of the filament is the chief source of microphonic noise. In the No. 264B Tube, therefore, the filament is made comparatively short and heavy and is mounted in the form of a broad, inverted V to whose apex considerable tension is applied by means of a cantilever spring. The effectiveness of this treatment may be seen from Table III which lists the mean noise levels for a number of types of Western Electric small tubes, and the maximum and minimum

TABLE III*

Class	No. of Samples Tested	Type Number	Microphonic Noise Level in db below 1 volt			
			Measured output Level			Equivalent Mean Input Level
			Max.	Min.	Mean	
Filament type triode	250	101D	23	38	32	47
	833	101F	8	30	19	35
	505	102F	9	36	20	46
	235	215A	12	42	27	41
	1,144	231D	2	28	16	33
	201	239A	4	36	22	37
	715	264B	30	52	42	58
Indirectly heated cathode type triode	99	244A	28	48	39	58
	448	247A	26	52	42	64
	452	262A	36	62	49	71
Screen grid and pentode	24	245A	18	39	29	63
	42	259A	2	36	20	61
	30	283A	4	42	21	62
	30	285A	12	30	23	57

* The microphonic properties of the No. 259A Tube given in this table are identical with those of the 259B discussed by Pearson.[5]

levels which have been observed for each type. The No. 264B, with a mean level of 42 db below 1 volt, is 20 db quieter than the No. 239A which it was designed to replace, and is the quietest of the filament type triodes. The next quietest tube of this structure is the No. 101D, in which the elements are supported from a rigid glass arbor and the filament is quite heavy, requiring one ampere of heating current. The No. 215A is almost identical with the No. 239A except for a firmer supporting structure which results in a 5 db improvement. The most microphonic of the types listed is the No. 231D, which has a very fine wire filament whose diameter is fixed by the requirement that the heating current be 0.060 ampere.

If the filament is the chief source of microphonic noise in filament type tubes, then it is to be expected that tubes having indirectly heated cathodes will be much less microphonic, inasmuch as the cathode is an extremely rigid member. An examination of Table III shows that this is indeed true. The No. 244A and No. 247A types, in which no special precautions have been taken to obtain quietness, are about as quiet as the No. 264B Tube. In the No. 262A Tube, therefore, it has been possible to reduce the microphonic noise still further, to 49 db below 1 volt, by cementing the elements into rigid supporting blocks of ceramic material. This tube is also quiet in other respects, notably in its freedom from AC hum picked up from the cathode heater circuit.[7]

In comparing tubes having widely different electrical characteristics, it is not quite fair to compare their noise output levels alone, for given two tubes having the same noise output, the tube having the higher gain can be used with smaller signal inputs and have no greater noise interference in the output. Accordingly, another column is given in Table III listing the equivalent noise input level which would produce the observed noise output if the tube itself were perfectly quiet. The ratio of this value to the signal input level is directly related to the degree of microphonic noise interference which is effective in the output of the tube. It is computed by adding the voltage gain expressed in db, of the tube in the measuring circuit, to the microphonic output level obtained experimentally. The value of this criterion is illustrated in comparing the noise interference produced by multi-element tubes and triodes. Multi-element tubes as a rule have higher noise output levels than triodes as may be seen by comparing the Nos. 245A, 259A, 283A, and 285A screen-grid and pentode types with the Nos. 244A, 247A, and 262A triodes. When account is taken of the higher voltage amplification of these former types, however, the noise inter-

[7] "Analysis and Reduction of Output Disturbances Resulting from the Alternating Current Operation of the Heaters of Indirectly Heated Cathode Triodes," J. O. McNally, *Proc. I.R.E.*, v. 20, pp. 1263–83, August, 1932.

ference as indicated in the equivalent input noise column of the table, compares quite favorably with that of the triodes.

From the point of view of the user of vacuum tubes, constrained to work with available types, the most effective means of microphonic noise reduction is the use of one of the quieter types of tubes which have been described. In cases where noise difficulties are experienced in existing apparatus not readily convertible to the use of a quieter type of tube, however, some relief may be gained by selecting the quieter tubes from a number of the type to be used. To be fully effective, the selection should be based on measurements made while the tube is in the socket in which it actually works. Under such circumstances, the measurements are reliable to within about 5 db.

Where selection in the field is not feasible, a smaller degree of relief may still be gained by selection at the factory. The degree of effectiveness of this method can be deduced from Fig. 4. Suppose, for example, that quiet tubes for service on the apparatus rack are to be selected by a test made on the continuous tapper. Choosing the best 25 of the group as tested by the continuous tapper (those plotted above the horizontal line in the figure), it is immediately obvious that when these selected tubes are tested on the apparatus rack (compare abscissae in Fig. 4) the worst tubes are somewhat quieter than some of those in the remaining portion of the group. This is more clearly shown in Fig. 8

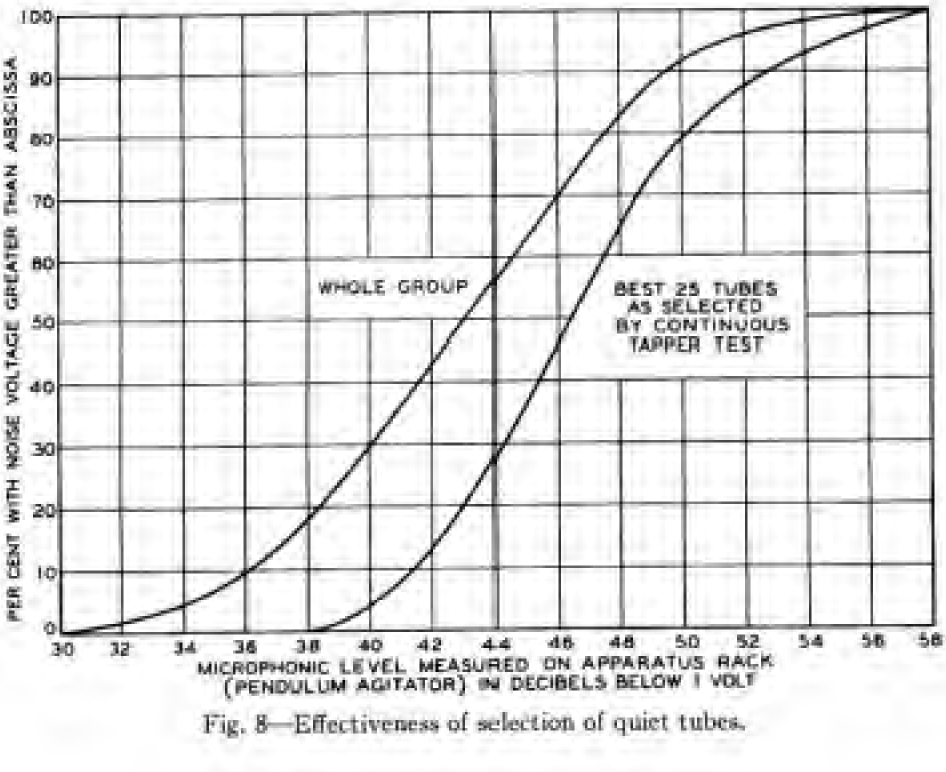

Fig. 8—Effectiveness of selection of quiet tubes.

in which the distribution of levels in this group of 25 tubes is compared with that of the total group as tested on the apparatus rack. The noisiest tubes in the selected group are from 6 to 8 db quieter than the noisiest tubes of the unselected group, and in the selected group, there are none of the tubes which make up the worst 18 per cent of the whole group.

In several commercial situations where microphonic disturbance was at one time troublesome, this type of selection has proved to be of practical value. In these situations, the number of quiet tubes required is only a small percentage of the manufactured output. Furthermore, only a small percentage of the normal output of tubes are found to be prohibitively noisy. Under such circumstances, it is found that when selected tubes from the quietest 25 per cent of the manufacturers stock are used in the positions most sensitive to mechanical shock, the disturbance in these types of equipment either disappears entirely or recedes to such a level that it is no longer troublesome.

Protection from Shock

Where selection of quieter tubes is not feasible or is not sufficiently effective, further reduction of microphonic noise may be achieved by protecting the tube from mechanical and acoustic shock. A very efficient agency for protection from mechanical shock is a well-designed cushion socket. The effectiveness of such a socket depends on its vibrational transmission characteristics considered in relation to the response characteristics of the tubes used. Considerable improvement is usually obtained, however, whatever the combination of tube type and socket type. Figure 9 shows two typical cases of microphonic improvement obtained by using one of several good types of cushion socket which have been tested. The curves drawn in solid lines represent the distributions of microphonic noise levels of a group of No. 102F Tubes tested in one instance in a rigid socket, and in the other in a cushion socket. The mean improvement here due to the cushion socket, is about 30 db. The dotted curves represent similar tests made on a group of No. 262A Tubes and show a mean improvement of about 18 db.

In cases where the noise must be reduced to very low levels, it may not be sufficient to protect the tube from disturbances transmitted mechanically through its base and socket. Except in a perfectly quiet location, there is always some disturbance produced by sound waves impinging directly on the bulb of the tube. Ordinarily this disturbance is negligible, but where the base is sufficiently well cushioned, it may be of controlling importance. It can be reduced only by reducing

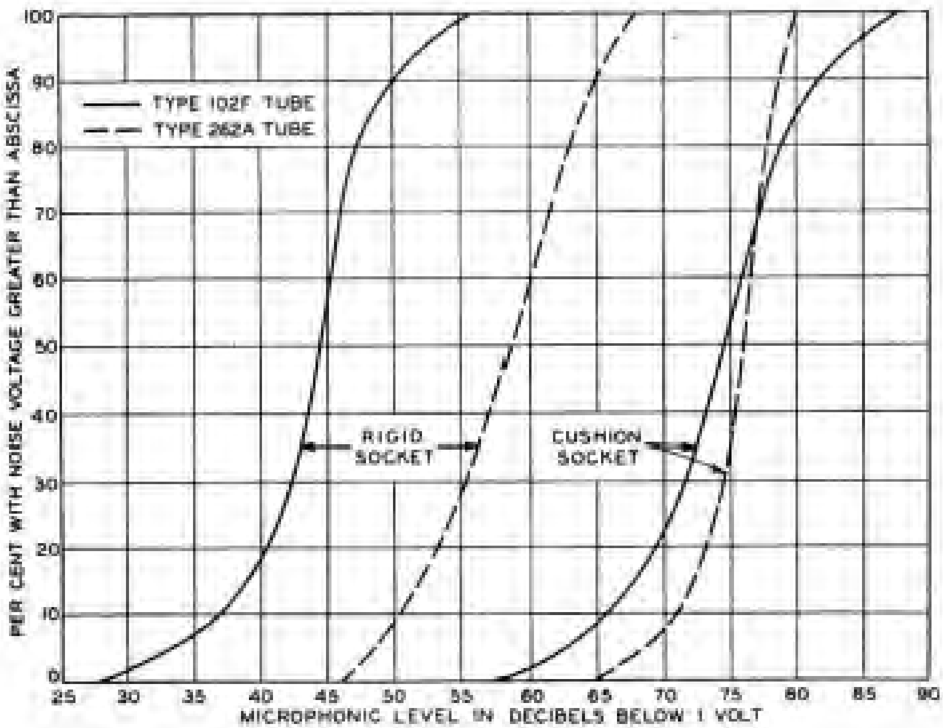

Fig. 9—Effect of cushion socket.

the intensity of the sound wave which is finally allowed to reach the tube, by some such means as enclosing the tube in a heavy, air-tight container.

Reduction of Sputter Noise

The reduction of sputter noise in vacuum tubes is chiefly a problem for the tube manufacturer. Where sputter noise exists in a tube, and exists only with agitation, it is often eliminated by the same cushioning measures which are applied to reduce microphonic noise, but in many cases, satisfactory reduction of sputter would require prohibitive amounts of cushioning. Fortunately, however, the known design features and manufacturing methods, which are now generally applied to tubes of good design, are for the most part quite effective in reducing sputter noise to a negligible level. In the older types of filamentary tubes, for example, sputter noise was often present due to the rattling of the filament at the hook supports at operating temperatures. This source of sputter has been removed in most present day tubes by keeping the filament under tension at all times by means of flexible cantilever spring supports. The effectiveness of this treatment is illustrated in Fig. 10, which shows distributions of sputter noise levels for two

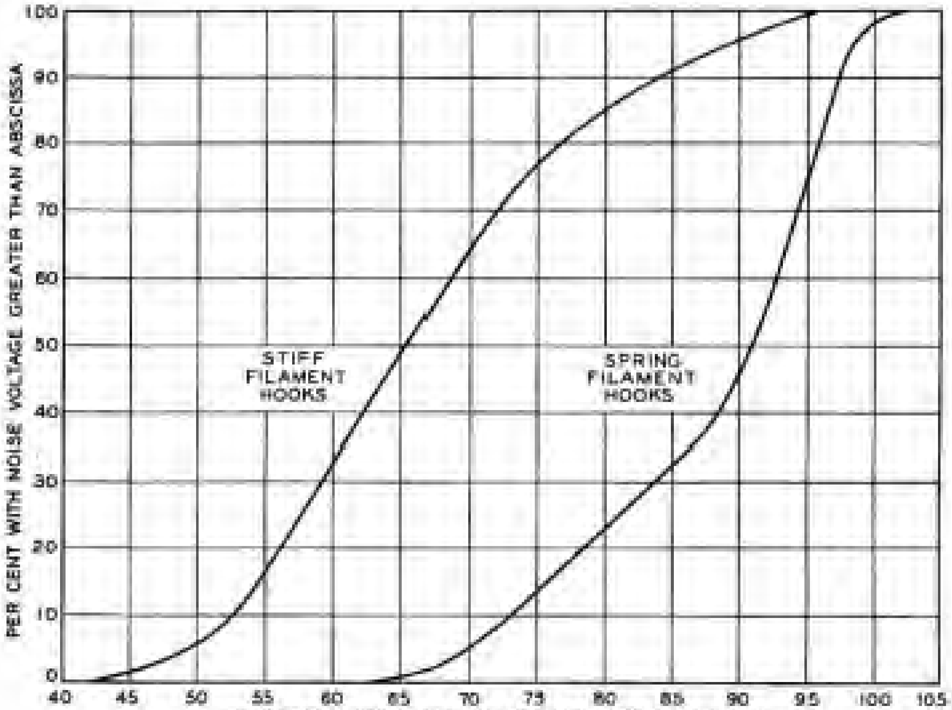

Fig. 10—Effect of filament looseness on sputter noise.

groups of tubes identical in every respect except that one group has spring filament supports while the other has the older rigid supports. In 80 per cent of the tubes, the improvement in the sputter noise is from 20 to 25 db when the spring hook is used.

The source of sputter noise most difficult to control in present day tubes is insulation leaks. These are commonly due to very thin films of conducting material which have been deposited on the surface of the insulating members by sputtering or evaporation during the exhaust or operation of the tube. Experience has shown the conductivity of these films to be intrinsically unstable and discontinuously variable. This condition alone can and does produce sputter noise, but to make matters worse, the metal support wires of the tube are often in only loose contact with the insulating parts and the conducting films covering them so that mechanical agitation breaks and makes the contact and increases the intensity of the noise. The reduction of these insulation leaks is largely a matter of choice of materials, of manufacturing technique to reduce the evaporation of conducting material during exhaust, and of mechanical design to shield important surfaces from contamination during the normal operation of the tube. Great prog-

ress has been made in recent years in effecting an adequate reduction of leaks economically, and in applications where requirements for exceptionally low noise levels warrant slightly increased manufacturing costs, almost any degree of reduction of leaks may be obtained.

Conclusion

The methods which have been outlined for reducing microphonic noise by cushioning and by making use of the quiet tubes which are available are, for the present, adequate to meet all but the most extreme requirements. Should the necessity for further reduction become sufficiently urgent in the future, however, it can probably be obtained either by designing still quieter tubes or by improving the cushioning of sockets. The latter course appears to be the more economical. In either case, however, greatest effectiveness can be attained by considering particular types of tubes and sockets in their relation to one another.

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